THE “CESM” MELTPOND PARAMETERIZATION IN CICE

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1. Overview

The CESM meltpond parameterization tracks melt pond volume, assuming pond shape and using empirical formulas for physical melt pond processes [1]. These processes, described in more detail below, include addition of liquid water from rain, melting snow and melting surface ice, drainage of pond water when ponds become deep relative to the sea ice thickness, and refreezing of the pond water. Radiatively, the surface of an ice category is divided into fractions of snow, pond and bare ice. The presence of snow on the sea ice may mask the ponds by reducing the pond area fraction used for the radiation calculation.

Although the CESM implementation of this melt pond parameterization only carries pond volume as a tracer, both volume (or thickness) and pond area tracers are needed because other sea ice processes alter the ice area (and therefore the relative pond area) between the melt pond physics and shortwave calculations. CICE uses both tracers.

The basic conservation equations for ice area fraction a_i, pond area fraction $a_{pnd}a_i$ and pond volume $h_{pnd}a_{pnd}a_i$, given the ice velocity $\mathbf{u}$, are

$$\frac{\partial}{\partial t}(a_i) + \nabla \cdot (a_i \mathbf{u}) = 0, \tag{1}$$

$$\frac{\partial}{\partial t}(a_{pnd}a_i) + \nabla \cdot (a_{pnd}a_i \mathbf{u}) = 0, \tag{2}$$

$$\frac{\partial}{\partial t}(h_{pnd}a_{pnd}a_i) + \nabla \cdot (h_{pnd}a_{pnd}a_i \mathbf{u}) = 0. \tag{3}$$

Equation (3) expresses conservation of melt pond volume, but in this form highlights that the quantity tracked in the code is the pond depth tracer h_{pnd}. Likewise, a_{pnd} is a tracer on ice area (Eq. 2).

For a generic quantity q that represents a mean value over the ice fraction, qa_i is the average value over the grid cell. Thus h_{pnd} can be considered the actual pond depth, $h_{pnd}a_{pnd}$ is the mean pond depth over the sea ice, and $h_{pnd}a_{pnd}a_i$ is the mean pond depth over the grid cell.

Throughout this documentation, equations represent quantities within one thickness category; all melt pond calculations are performed for each category, separately.

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2. Meltpond Processes

2.1. **Melt water.** A volume ΔV_{melt} of melt water produced on a given category may be added to the melt pond liquid volume:

$$\Delta V_{melt} = r\left(\rho_i \Delta h_i + \rho_s \Delta h_s + F_{rain}\Delta t\right) a_i,$$

where $r = r_{min} + (r_{max} - r_{min})\, a_i$ is the fraction of the total melt water available that is added to the ponds, ρ_i and ρ_s are ice and snow densities, Δh_i and Δh_s are the thicknesses of ice and snow that melted, and F_{rain} is the rainfall rate.

2.2. **Refreezing of ponds.** If the surface temperature T_{sfc} (computed in the sea ice thermodynamics routine) is colder than $T_d = -2°\text{C}$, then a volume ΔV_{frz} is removed from the pond volume V_p:

$$\Delta V_{frz} = -V_p\left(1 - e^{0.01\left(T_d - T_{sfc}\right)/T_d}\right).$$

2.3. **Pond shape.** At this point in the calculation, the area and depth of the ponds are computed using an assumed aspect ratio, or shape, given by the parameter δ_p (`pndaspect`), $\delta_p = h_{pnd}/a_{pnd}$ and $V = h_{pnd}a_{pnd} = \delta_p a_{pnd}^2 = h_{pnd}^2/\delta_p$.

2.4. **Drainage.** Pond depth is limited such that $h_{pnd} \leq 0.9 h_i$.

2.5. **Snow infiltration by pond water.** Snow on sea ice may hide the pond, reducing its radiative effects. Thin layers of snow on pond ice are assumed to be patchy, thus allowing the shortwave flux to increase gradually as the layer thins. This is done using the simple parameterization

$$a'_{pnd} = \left(1 - \min\left(h_{ps}/h_{s0}, 1\right)\right) a_{pnd}a_{lvl}.$$

3. Tracer dependencies and conservation

The tracer indices `nt_apnd` and `nt_hpnd` (for a_{pnd} and h_{pnd}, respectively) are declared in **ice_state.F90** and initialized in **ice_init.F90**, and their dependencies are set such that a_{pnd} depends on a_i, and h_{pnd} depends on a_{pnd}. Note that if a quantity such as a_i or a_{pnd} becomes zero in a grid cell's thickness category, then all tracers that depend on it also become zero.

The processes described above are implemented in **ice_meltpond_cesm.F90** and **ice_shortwave.F90**. Aside from the meltpond physics, the tracers may need to be modified for proper conservation during other sea ice processes. The conserved quantity is "tracer volume" $h_{pnd}a_{pnd}a_i$, not h_{pnd}. Conserved quantities are thus computed according to the tracer dependencies, and code must be included to account for the dependency on a_{pnd} in **ice_itd.F90** (subroutines *aggregate*, *shift_ice* and *compute_tracers*) and subroutine *ridge_shift* in **ice_mechred.F90**.

There are two more cases in which the tracers need to be modified for physical reasons, namely when ice ridges and when new ice forms in open water. For example, when sea ice deforms, a fraction of the pond water proportional to the amount of ice ridged is lost to the ocean.

When new ice forms in open water, it does not yet have ponds on top of it. Therefore the fractional coverage of ponds on sea ice decreases (thicknesses are unchanged). This is accomplished in **ice_therm_itd.F90** (subroutine *add_new_ice*) by maintaining the same mean pond area in a grid cell after the addition of new ice,

$$a'_{pnd}(a_i + \Delta a_i) = a_{pnd} a_i,$$

and solving for the new pond area tracer a'_{pnd} given the newly formed ice area Δa_i.

4. Parameters

Parameters available in the namelist file for controlling the parameterization.

variable	options/format	description	CESM value
tracer_nml		*Tracers*	
`tr_pond_cesm`	true/false	level-ice melt ponds	`.true.`
`restart_pond_cesm`	true/false	restart tracer values from file	
ice_nml		*Physical Parameterizations*	
`rfracmin`	$0 \le r_{min} \le 1$	minimum melt water added to ponds	0.15
`rfracmax`	$0 \le r_{max} \le 1$	maximum melt water added to ponds	0.85
`pndaspect`	real	aspect ratio of pond changes (depth:area)	0.8
`hs0`	real	snow depth for transition to bare ice	0.03 m

5. Index of melt pond history and restart variables

Fields with the suffix '_ai' are means over the grid cell. Other fields are given as averages over the ice fraction.

apeff	effective area fraction of ponds	
apond	area fraction of ponds	
apond_ai	area fraction of ponds	
apondn	area fraction of ponds (category values)	
hpond	depth of ponds	m
hpond_ai	depth of ponds	m
melts	snow melt rate	cm/day

The tracer arrays indexed with `nt_apnd` and `nt_hpnd` (a_{pnd} and h_{pnd}) are saved in melt pond restart files.

References

[1] M. M. Holland, D. A. Bailey, B. P. Briegleb, B. Light, and E. Hunke. Improved sea ice shortwave radiation physics in CCSM4: The impact of melt ponds and aerosols on arctic sea ice. *J. Clim.*, 2012. doi: 10.1175/JCLI-D-11-00078.1, in press.